

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF RESEARCH ADMINISTRATION

Date: 1 February 1967

RESEARCH PROJECT INITIATION

Project Title: **Transient Film Boiling on a Horizontal Cylindrical Surface**

Project No.: **B-1103**

Project Director: **Dr. Thomas W. Jackson**

Sponsor: **National Science Foundation**

Agreement Period: From 15 February 1967 until approximately 14 February 1969

Type Agreement: **Grant No. GK-1416**

Amount: \$26,500 NSF Funds (B-1103)
 6,508 GIT Contribution (E-1102)
 \$33,008 Total Budget

Grant Administrator

Dr. John M. Ide
Division Director for Engineering
Division of Engineering
National Science Foundation
Washington, D. C. 20550

Reports Required

Annual - 14 February 1967
Final - Upon completion of project

Assigned to: School of Mechanical Engineering

COPIES TO.

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Other File B-1103

72
B448

GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT TERMINATION

Date: June 15, 1970

Project Title: Transient Film Boiling on a Horizontal Cylindrical Surface

Project No: B-1103

Principal Investigator: Dr. Thomas W. Jackson

Sponsor: National Science Foundation

Effective Termination Date: February 15, 1970

Clearance of Accounting Charges: Completed March 2, 1970

Final Report Submitted: February 14, 1970

COPIES TO:

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Terminated Project File No. B-1103

Other _____

National Science Foundation

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14 February 1970

If you have any questions concerning the final report, please let me know.

Sincerely yours,

Thomas W. Jackson
Professor of M.E.
Georgia Institute of Technology

TWJ:djm

Enclosure: Final Report NSF Grant GK-1416

cc: Dr. S. P. Kezios (1 copy)
Director - School of M.E.
Georgia Institute of Technology

Mr. H. L. Baker, Jr. (2 copies)
Director of Research Administration
Georgia Institute of Technology



SKIDAWAY INSTITUTE OF OCEANOGRAPHY

UNIVERSITY SYSTEM OF GEORGIA

55 WEST BLUFF ROAD

SAVANNAH, GEORGIA 31406

14 February 1970

National Science Foundation
Washington, D. C. 20550

Attention: Dr. Royal E. Rostenbach, Program Director
Engineering Energetics, Engineering Division

Subject: Final Report on Grant No. GK-1416
Entitled - Transient Film Boiling on a Horizontal Cylindrical
Surface.

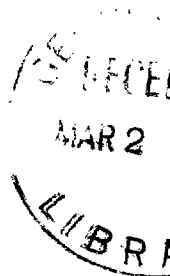
Gentlemen:

In accordance with your requirements I am enclosing a brief final report on the subject research. Detailed descriptions of the research effort of the students who have worked on the project are contained in the theses and published papers which have previously been forwarded to the National Science Foundation.

As indicated in the final report, I still have one student, Mr. David P. Wehmeyer, working on transient boiling. He has defended his thesis and it has been approved provided he makes certain changes as indicated by his committee. He will not be required to stand for another oral examination on the thesis. We anticipate that the changes can be completed in a month or so and will forward you a copy of this thesis when it is finally accepted.

I have requested the Director of Research Administration at the Georgia Institute of Technology to forward the Foundation a financial statement on the project. I hope this is satisfactory.

I would like to take this opportunity to commend the personnel of the Engineering Division for their cooperation in administering the subject grant and their interest in graduate research. The grant has contributed substantially to the graduate program of the School of Mechanical Engineering at Georgia Tech. It has made it possible for four young men to embark upon careers in research. Personally I have enjoyed working with the Foundation and the students on the subject grant.



FINAL REPORT - NSF GRANT # GK-1416

"Transient Film Boiling on a Horizontal Cylindrical Surface"

14 February 1970

Introduction

The research covered by the subject grant was initiated to investigate transient film boiling on a horizontal cylindrical surface. The primary object of the research was to determine the rate of film growth as a function of fluid properties, excess temperature, and time. Initially water was used as the fluid medium and film growth rates were obtained upon a horizontal cylindrical wire both in the saturated and sub-cooled conditions. At a later date, research was initiated to determine the rate of film growth when the wire was surrounded by a cylindrical shell. At still a later date, an effort was made to determine the film growth rate for fluids other than water; namely, carbon tetrachloride and freon.

The interest in the subject research stemmed from the possibility of metering small volumes of gasoline or other fluids in periodic amounts by means of boiling heat transfer. In addition, a widespread interest existed concerning transient boiling behavior because of control and response problems of some thermal systems, namely nuclear power reactors.

The subject research was initiated on 15 February 1967. During the past three years four doctoral students have worked on the project. Mr. Don R. Pitts dealt with transient film boiling of distilled water at, or very close, to saturation conditions from small diameter, horizontal, electrically heated, platinum wires. He initiated an approximate step change in temperature by rapidly discharging the energy from an electrical capacitor through the wire. The final wire temperature was obtained in the order of 50 micro-seconds and was measured by Mr. Pitts by means of a calibrated Wheatstone bridge, the wire being one leg of this bridge. An oscilloscope system allowed the transient conditions to be measured. The transient film growth was recorded by means of high speed (4000 frames per second) motion pictures.

Mr. Pitts used wire sizes of 10 mils and $12\frac{1}{2}$ mils. He ran a total of 12 experiments covering a range of excess temperature from 1019 to 1529 degrees F. Mr. Pitts found that the resulting vapor growth could be described as approximately cylindrical for an excess temperature greater than 1000 degrees F., but could not be so described for lower temperatures. He also found that the transient cylindrical growth usually lasted for approximately 10 milliseconds, after which the onset of large bubble formation on the wire was evident. The motion picture films gave evidence of vigorous nucleate boiling during the first fraction of a millisecond of each test. The phenomenon was not peculiar to platinum surfaces but was also obtained on a high purity gold wire heater element. Mr. Pitts' analysis predicted vapor growth rate for saturated pool transient

film boiling from a horizontal cylindrical surface.

Following Mr. Pitts, Mr. Howard H. Yen conducted an analytical and experimental investigation to determine the transient film growth during the initial regimes of transient film boiling from a horizontal wire in a sub-cooled liquid. Mr. Yen's analytical analysis gave a solution for the local temperature distribution in the sub-cooled liquid phase. Incompressible radial flow was assumed in this analysis. Yen's solution of the energy equation gave the temperature distribution as a function of the incomplete gamma function. He assumed constant heat flux from the heat source in the analysis.

Mr. Yen's experimental program was carried out for distilled water in various degrees of sub-cooling from small diameter, horizontal, electrically heated, platinum wires. An approximate step change in wire temperature was again accomplished by a rapid discharge of energy from an electrical capacitor into the heating element. The equipment Mr. Yen used was similar to that used by Dr. Pitts. The wire sizes studied by Mr. Yen were 9.8 mils and 12.6 mils in diameter. Mr. Yen covered a range of sub-cooling from 5 to 43 degrees F. A greater degree of sub-cooling would not permit the film to grow sufficiently to record valid or meaningful data.

Yen's analytical results confirmed his experimental findings. He observed that the film boiling was preceded, as was noted by Mr. Pitts, by vigorous nucleation for large heating surface temperature changes. This nucleation had a profound effect upon the ensuing rate of vapor formation if the bulk fluid temperature was near the saturation condition, but the effect decreased as the degree of sub-cooling was increased.

Mr. Everett Richards followed Mr. Yen and conducted an analytical and experimental investigation to determine the transient film growth during the initial 10 milliseconds of transient film boiling in a horizontal annulus. The annulus was initially filled with saturated water. Heating was from the inner surface and the annulus was open at both ends. The inner surface of the annulus was formed by the heating element which again was platinum wire. Elements of 8 mils and 10 mils diameter were used. A close approximation to a step change in element temperature was achieved by discharging a capacitor across the element in a manner similar to that used by Mr. Pitts and Mr. Yen. The outer surface of the annulus was formed by a hole drilled in a block of plexiglass. Annuli having outer diameters of 32, 70, and 101 mils were used. Excess temperatures from 1208 to 1792 degrees F. were obtained. High speed motion pictures again were taken to obtain data on the vapor film growth rate and again vigorous nucleate boiling occurred during the initial few micro-seconds of each run. This nucleate boiling had a strong effect on the total vapor formed during an experiment. It was also found that larger tube diameters and larger element diameters resulted in increased rates of film growth. The analytical results were in good agreement with the experimental results.

The three men listed above have completed all of the requirements for Ph.D. degrees at the Georgia Institute of Technology. One is teaching at Tennessee Tech, one is working at the U. S. Navy Mine Defense Laboratory, and the third is a senior research engineer at the Skidaway Institute of Oceanography.

Mr. David Wehmeyer utilizing the same basic equipment as the foregoing men initiated a program to study the transient film boiling using various fluids. Mr. Wehmeyer was concerned with both an analytical and an experimental investigation of transient film boiling on a horizontal wire in various saturated liquids. Radiation effects were considered analytically, because radiation effects could not be determined experimentally. Mr. Wehmeyer conducted experiments with carbon tetrachloride and freon. He formulated a mathematical model which assumed that the film growth is in a radial direction only and results in a vapor cylinder of uniform cross section. He obtained experimental data on the rate of growth of the vapor film for carbon tetrachloride and freon during the first 10 milliseconds after discharge of the capacitors.

Mr. Wehmeyer has taken his final examination on his doctoral thesis and after correcting and modifying the thesis, in accordance with instructions from his examining committee, will have completed all the requirements for a doctor's degree at the Georgia Institute of Technology. It is anticipated that this work will be completed in the next few months. A copy of the thesis and any resulting papers will be forwarded to the National Science Foundation when they are available.

Description of Research

The experimental research apparatus, which was briefly described above, consisted of a small horizontal wire immersed in the liquid under consideration. The wire may or may not be surrounded by a plastic confining shell. In operation the experimental system had a main capacitor charged to the desired voltage. This capacitor was then discharged rapidly across the wire in the test fluid. The discharge, in the order of 50 micro-seconds, raised the wire temperature to the desired value and initiated the boiling phenomena which ranges from nucleate to the transient state. A Hycam camera was used to take the pictures of the growth of the vapor film. When the wire was confined in a cavity, the evacuation of fluid in the cavity could also be noted from the photographic data. The wire temperature as measured by a complicated Wheatstone bridge arrangement which could be calibrated prior to the experimental run. A complete description of the equipment procedures is available in Dr. Pitts', Dr. Yen's, or Dr. Richards' theses.

Grant Activities

During the course of this experimental investigation the following doctoral theses have been accepted by the Graduate Division of Georgia Tech:

1. "Transient Film Boiling on a Horizontal Cylindrical Surface" by D. R. Pitts - August 1967.
2. "Transient Film Boiling on a Horizontal Cylindrical Surface in a Sub-cooled Liquid" by Howard Hong-Yuang Yen - July 1968.

3. "Transient Film Boiling in a Horizontal Annulus Filled with a Saturated Liquid" by Everett L. Richards - June 1969.

The following papers have been published or accepted for publication:

1. "Transient Film Boiling of Water on a Horizontal Wire" by D. R. Pitts, H. H. Yen, and T. W. Jackson, Presented at 10th National Heat Transfer Conference and published in the Transactions of the ASME, Journal of Heat Transfer, Vol. 90, Series C, No. 4, November 1968, pp 476-481.
2. "Sub-cooled Transient Film Boiling of Water on a Horizontal Wire" by H. H. Yen, T. W. Jackson, and D. R. Pitts, 11th National Heat Transfer Conference, PROGRESS IN HEAT AND MASS TRANSFER, Vol. 2, Pergamon Press, 1969, pp 295-309.
3. "A Simplified Solution for Transient Film Boiling with Constant Heat Flux" by T. W. Jackson and H. H. Yen. Accepted for Fourth International Heat Transfer Conference, Aug. 31 - Sept. 5, 1970, Paris, France.

In addition to the above it is anticipated that one additional doctoral thesis will be completed by Mr. David P. Wehmeyer. Because the subject grant does not have any remaining funds it is suggested that it be terminated at this time. A copy of the financial statement on the grant will be provided by the business office of Georgia Tech.

Miscellaneous

The subject grant has contributed substantially to the Graduate Program of Georgia Tech. The support which it gave to the four doctoral students is deeply appreciated.

Respectfully submitted

Thomas W. Jackson
Project Director - Prof. of M.E.
Georgia Institute of Technology
Atlanta, Georgia 30332

TWJ:djm

cc: Dr. S. P. Kezios
Director - School of M.E. - Ga. Tech.

(2) Mr. Harry L. Baker, Jr.
Director - Research Administration - Ga. Tech.